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RESEARCH ON RADIATION HEAT SHIELDS FOR BODIES AND LEADING EDGES

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TECHNICAL MEMORANDUM X-312

RESEARCH ON RADIATION HEAT SHIELDS FOR BODIES AND LEADING EDGES*

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SUMMARY

Two types of radiation heat shields designed for protection of the primary structure of a lifting reentry vehicle are discussed. The shields considered are body heat shields for protection of large areas of the vehicle and leading-edge heat shields for protection of the more severely heated stagnation areas. Results of research on body shields fabricated from super-alloy materials are given, and problems associated with construction of similar shields of refractory metals are indicated. Some preliminary results are presented from arc-jet tests made on leading edges fabricated of graphite and pyrolytic-graphite materials.

INTRODUCTION

The discussion of heat protection systems in reference 1 has indicated the need for some form of radiating heat shield for the most severely heated portion of a lifting reentry vehicle. Two types of heat shields are considered for this purpose and might be placed as shown in figure 1: body heat shields to protect a large area of the vehicle and leading-edge and nose shields to protect stagnation areas where the heating is most intense. The heat shield must withstand the reentry environment but is separated from the load-carrying functions of the underlying primary structure. This separation of functions allows the heat shield to be designed to the upper temperature limits of the material and the primary structure to be designed principally to meet the load requirements. For example, a body shield fabricated from one of the superalloys might operate at 2,200° F while protecting a cooled aluminum structure operating at 100° F to 200° F. Heat shields may be considered as secondary structure and as such pose several unique design problems. Because of the differences in heating between the body and the leading edges, the solutions for these problems take on different forms and are discussed separately. Body heat shields are treated first and leading-edge heat shields, second. Particular designs which have reached an

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advanced state of development or have undergone preliminary experimental investigation are discussed.

BODY HEAT SHIELDS

Some of the important requirements for a body heat shield are as follows:

(1) Light weight must be provided.

(2) High temperatures must be sustained.

(3) Thermal expansion must be absorbed.

(4) Air loads must be supported and stable conditions maintained in the airstream.

(5) Construction in refractory metals must be possible.

For the protection of a reentry vehicle, minimum weight is an important criterion. The heat shield must withstand high temperatures and absorb thermal expansion of as much as 1/8 inch per foot without overstressing or distorting the shield or primary structure. The shield must support some air loads and be stable for all conditions of reentry heating and aerodynamic loading. Additionally, construction in refractory metals will be required to withstand temperatures between 2,200° and 3,000° F.

Two types of shields which can meet most of these requirements are shown schematically in figure 2. The first, denoted as a panel shield, consists of stiffened panels such as honeycomb sandwiches, arranged in rectangular arrays and supported by a minimum number of attachments. Thermal expansion is permitted by the spacing between panels. The second shield design consists of a single sheet that can accommodate expansion locally by some device, such as corrugating or dimpling, which reduces the number of expansion joints required. A single-skin design can have a weight advantage over a stiffened panel; however, some loss in insulating efficiency results because of the need for more attachments.

Figure 3 depicts a panel heat shield which has been developed by the Bell Aircraft Corporation. The honeycomb panel is supported by flexible clips at each corner to permit thermal expansion. Shiplap joints between panels allow movement of each panel with respect to the others. Shield weight including supports is about 0.9 lb/sq ft.

The proper accommodation of thermal expansion was a difficult design problem. Panels which were held in place by retaining straps or by screws

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in oversized holes had a tendency to bind and not to allow the expansion desired. The panels of the final design are on firm supports yet offer little restraint of expansion to adjacent panels. Extensive work has also been done in minimizing heat paths from shield to structure, which has resulted in a heat shield with high insulating efficiency.

L-1076

This panel, which is constructed of a cobalt-base alloy (Haynes alloy no. 25), is in an advanced state of development and has successfully withstood the heating tests, wind-tunnel tests, noise tests, and flight tests indicated in the following table:

(1) Heating tests:	
(a) Maximum temperature, $^{\circ}$F	2,200
(b) Temperature difference between shield and water cooled structure, $^{\circ}$F	2,000
(c) Temperature rate, $^{\circ}$F/sec	50
(2) Wind-tunnel tests:	
(a) Mach number range	0.7 to 4.0
(b) Dynamic pressure, lb/sq ft	2,000 to 6,000
(3) Noise test:	
(a) Noise level for $10\frac{1}{2}$ hr, db	144
(b) Noise level for additional 1/2 hr, db	148
(4) Flight tests (several panels mounted and flown on large bomber):	
(a) Time at subsonic or transonic speed, hr	19.5
(b) Time at supersonic speed, hr	2.5
(c) Total time, hr	22.0

The cobalt-base alloy from which the panel was fabricated can sustain the maximum temperature shown in this table for only short times. The long-time temperature capability is about 2,000° F. Similar temperature capabilities apply to the other superalloys. This temperature limit may be extended by use of refractory metals, although fabrication of a refractory-metal honeycomb panel appears to be rather difficult. An alternate approach would be to fabricate a stiffened panel by resistance welding or mechanical fastenings. Both approaches require further investigation.

In order to obtain a simpler heat shield that might be more amenable to fabrication in refractory metals, a single-corrugated-skin heat shield has been undergoing development and tests at the Langley Research Center. The details of this shield are indicated in figure 4. The slightly corrugated skin allows thermal expansion in one direction. Expansion in the other direction is accomplished by flexure of the supports, which also serve as stiffeners for the primary structure. At the lap joint, one sheet is fastened to one stiffener and the adjacent sheet fastened to the other stiffener; thus, movement of the two sheets with respect to each other is allowed. The ceramic bushings at the attachments (shown by the darkly hatched areas) help insulate the structure and provide a solid foundation for mounting the shield. The range of dimensions shown was found to give satisfactory performance for the various tests made. This particular shield design with attachments weighs about 0.6 lb/sq ft. Figure 5 is a photograph of such a shield both before and after a series of heating and wind-tunnel tests. The tested panel surface has become oxidized and discolored from the heat but has undergone little distortion.

The environmental tests, which this shield and similar ones have undergone, are listed in the following table:

Heating tests:	
(a) Maximum temperature, °F	2,100
(b) Temperature difference between shield and structure:	
Transient conditions, °F	1,600
Steady-state conditions, °F	900
(c) Temperature rate, °F/sec	20
Wind-tunnel tests:	
(a) Mach number	3
(b) Dynamic pressure, lb/sq ft	3,000
(c) Stagnation temperature, °F	660

The heating tests and wind-tunnel tests imposed rather severe temperature and aerodynamic conditions on the heat shields. The ability of these heat shields to withstand these severe aerodynamic conditions as well as the high temperature is a strong indication that the heat shields could survive actual reentry. Because of the relative simplicity of construction, the extension of the temperature capabilities of such shields by use of refractory metals may be possible with the present state of knowledge, and this work is currently being pursued.

LEADING-EDGE SHIELDS

In the leading-edge stagnation area, equilibrium temperatures in excess of 3,000° F and maximum heating rates in excess of 100 Btu/ft^2-sec are expected. To meet these conditions, numerous leading-edge designs have been proposed and various materials have been suggested. Two configurations currently under investigation are illustrated in figure 6. The first configuration makes use of a large leading-edge radius which serves to reduce the maximum heating rate and thereby keeps the temperatures compatible with refractory-metal construction. Fabrication of such leading edges using coated molybdenum appears possible. A second approach utilizes nonmetallic materials which can withstand the more severe temperature and thermal shock conditions associated with smaller leading-edge radii. For this approach, tests by the Bell Aircraft Corporation have shown siliconized graphite to be a promising material. Full-scale leading edges of the nonmetallic type made of AGX graphite are presently undergoing tests at the Langley Research Center, and some preliminary results are presented herein.

The tests performed thus far have been made to determine whether a hardware item of reasonable size and shape can actually withstand the thermal environment expected on reentry. These tests were conducted in an arc-jet facility of the Langley structures research laboratory. Flow is subsonic (about 230 fps) and exhausts through a nozzle having a 2.5- by 12-inch rectangular exit. Temperature of the stream is about 9,000° F with an enthalpy of approximately 5,000 Btu/lb. Heating rates of 180 Btu/ft^2 and equilibrium temperatures in excess of 3,500° F were obtained on the 1-inch-radius AGX specimens.

L-1076

Figure 7 shows the particular leading-edge configurations investigated to date. The first type, shown at the top of the figure, was built to determine erosion rates and to determine whether simple graphite shells of 1-, 2-, and 3-inch leading-edge radii could survive the test conditions. The second type, shown at the lower left of figure 7 is representative of a plausible design with provision for attachment to the wing structure. Both designs were tested in 12-inch lengths. Tests have also been made on a 3-inch-long specimen machined from AGX graphite and then coated by vapor depositing pyrolytic graphite on the external surfaces to a thickness of either 1/16 or 1/8 inch (shown at lower right of figure 7). No delamination of the pyrolytic graphite or deleterious separations from the AGX substrate occurred during the tests.

Each type of specimen had a total thickness of 1/4 inch for the leading-edge shell. All specimens survived tests of up to 5 minutes duration without failure other than surface erosion or oxidation.

Figure 8 shows the variation with time of the temperature in back of the stagnation point for a typical test of two leading-edge specimens. One specimen was made entirely of AGX graphite (shown by the solid curve) whereas the other had a 1/8-inch coating of pyrolytic graphite. An equilibrium temperature of about 3,500° F was reached by the AGX graphite leading edge but thermocouple failure at 2 minutes prevented measurement of the equilibrium temperature for the pyrolytic-graphite specimen.

An unusual characteristic of pyrolytic graphite is that its thermal conductivity is much greater in the direction parallel to its surface

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than in the direction normal to its surface. The lower rate of temperature rise indicates that the conductivity of pyrolytic graphite normal to its surface is substantially less than that of AGX graphite.

Considerable erosion occurred during the tests as shown by the thickness loss at the stagnation point for the two specimens. (See fig. 8.) The circular symbols at 1 and 3 minutes were obtained from two other tests of similar AGX graphite leading-edge specimens. Less regression is shown for the pyrolytic graphite than for the AGX graphite leading edge. During many reentry flights peak temperatures on a highly
swept leading edge may not exceed 3,000° F, and erosion rates would be L
correspondingly smaller than that shown. Moreover, peak temperatures 1
would be sustained for only a part of the flight. Hence it is probably 0
feasible to make a graphite leading edge of sufficient thickness to sur- 7
vive a single reentry. However, it would be desirable to have highly 6
reliable oxidation resistant coatings so that a substantial weight saving could be realized.

CONCLUDING REMARKS

Results have been presented of tests made on shields designed to protect the body or the leading edges of a reentry vehicle. Body heat shields fabricated from the superalloys have been successfully subjected to various environmental conditions produced by heating, noise, and aerodynamic tests. In order to extend the temperature capabilities of such shields, work is in progress in adapting the proven designs to construction in refractory metals. For the stagnation areas, graphite and pyrolytic graphite leading edges have been built and successfully tested in an arc jet. Specimen temperatures of 3,500° F were sustained without failure. Surface erosion rates were high, although sufficient thickness could probably be provided to survive a single reentry.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., April 12, 1960.

REFERENCE

1. Anderson, Roger A., and Swann, Robert T.: Structures for Reentry Heating. NASA TM X-313, 1960.

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L-1076

HEAT-SHIELDED STRUCTURE

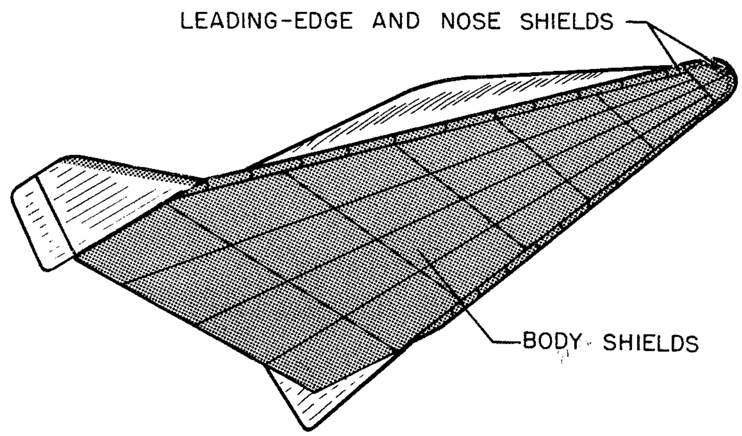

Figure 1

BODY-SHIELD DESIGN

REQUIREMENTS

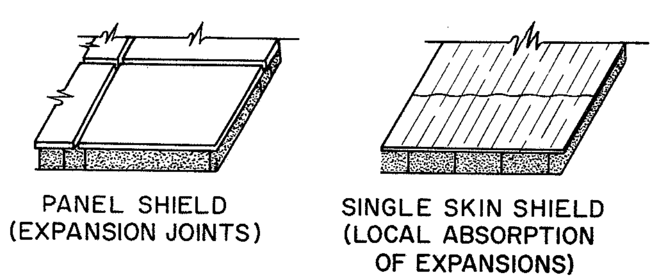

Figure 2

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HONEYCOMB-PANEL HEAT SHIELD
SHIELD WEIGHT, 0.9 PSF

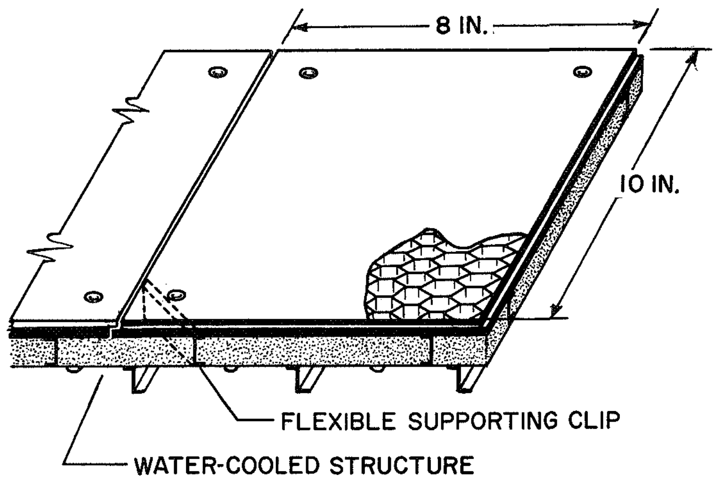

Figure 3

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DETAIL OF TYPICAL DESIGN TESTED
SHIELD WEIGHT, 0.6 PSF

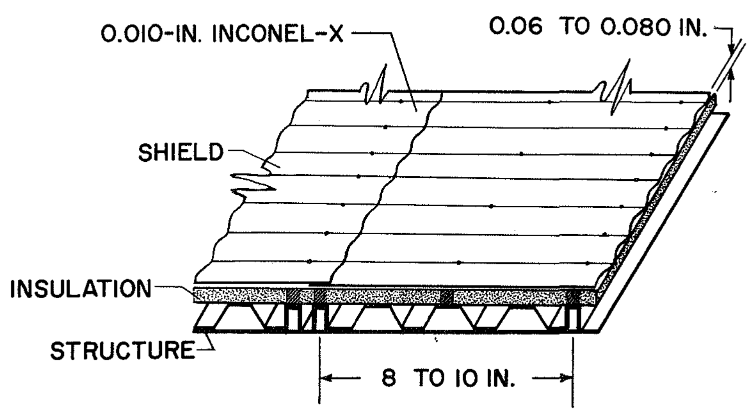

Figure 4

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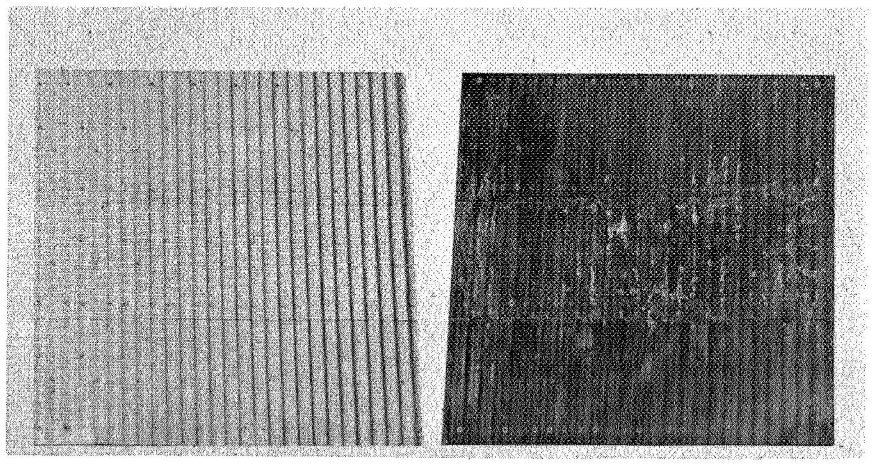
SINGLE-CORRUGATED-SKIN HEAT SHIELD



BEFORE TEST

AFTER TEST

Figure 5

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LEADING-EDGE CONCEPTS

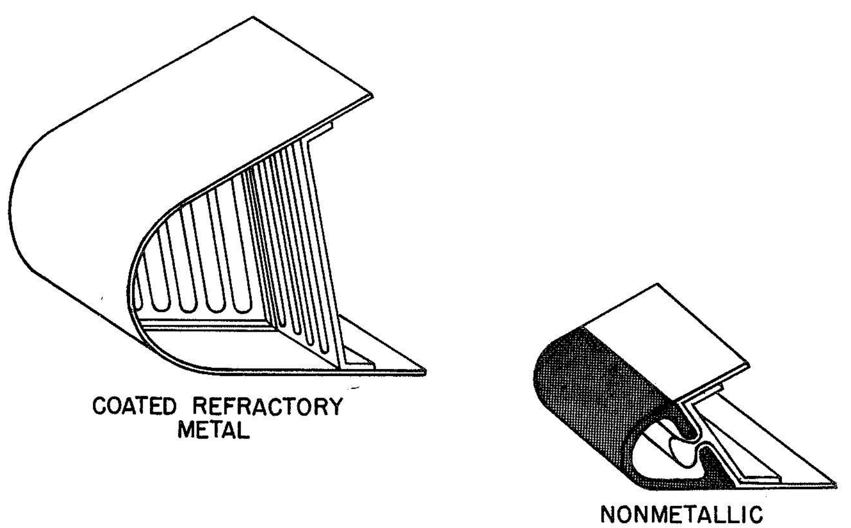

Figure 6

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GRAPHITE TEST SPECIMENS

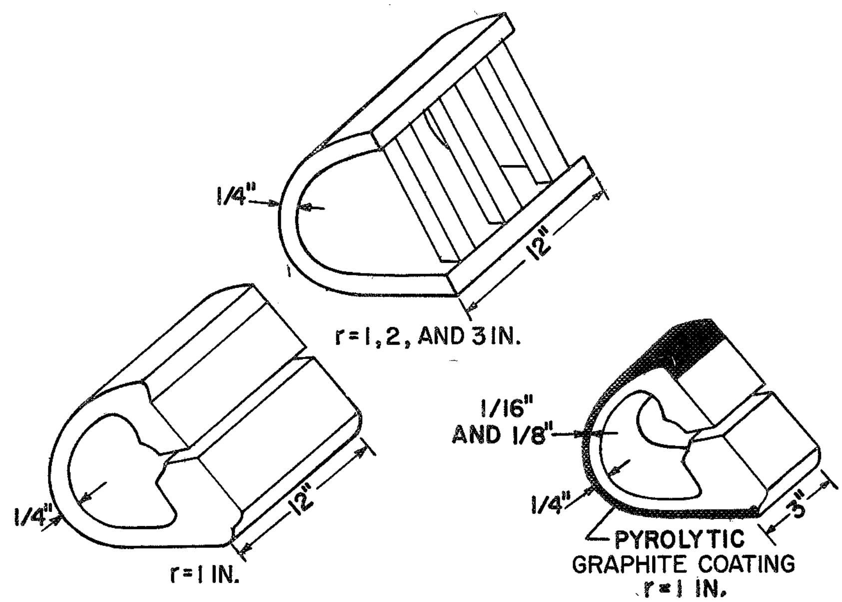

Figure 7

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GRAPHITE LEADING EDGE, ARC-JET TEST

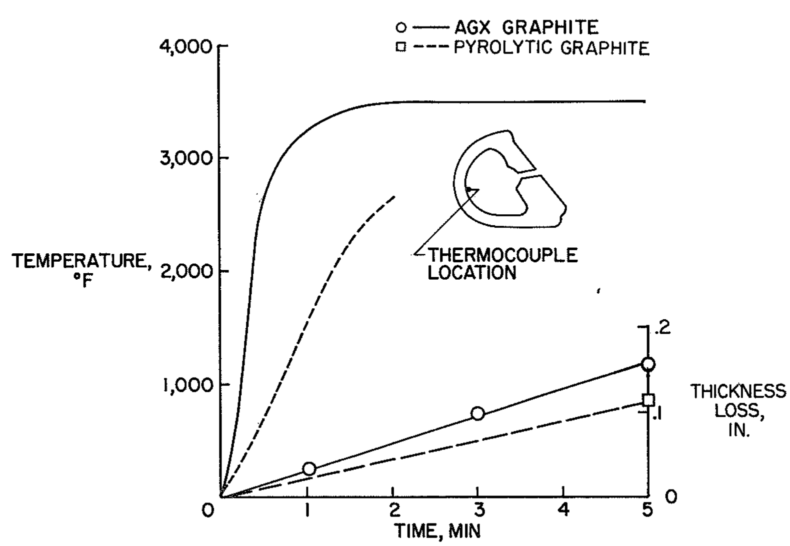

Figure 8

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